ERDC/CERL TR-05-38

Construction Engineering Research Laboratory

US Army Corps of Engineers®
Engineer Research and Development Center

Determining Research Gaps in Disturbance Data for Fort Bliss and a Conceptual Model

Tamara Hochstrasser, Debra Peters, and Jeffrey S. Fehmi

November 2005

ERDC/CERL TR-05-38
November 2005

Determining Research Gaps in Disturbance Data for Fort Bliss and a Conceptual Model

Tamara Hochstrasser and Debra Peters

USDA-ARS Jornada Experimental Range
Box 30003, MSC 3 JER
New Mexico State University
Las Cruces, NM 88003

Jeffrey S. Fehmi

Construction Engineering Research Laboratory
PO Box 9005
Champaign, IL 61826-9005

Prepared for Office of the Directorate of Environmental Programs (DAIM)
Assistant Chief of Staff (Installation Management) (ACS[IM])
Fort Bliss

ABSTRACT

Numerous research and outside monitoring efforts have been completed for Fort Bliss, Texas. This report summarizes results from previous experimental studies on military disturbances on Fort Bliss and identifies research gaps in disturbance data. These studies (and others) are used to develop conceptual models of the impact of military disturbances on vegetation dynamics in arid lands.

CONTENTS

PREFACE iv
1 INTRODUCTION 1
2 RESEARCH GAPS 2
MacKay and Herrick (1996) 2
Simulated track maneuver study (Jones et al. 1997) 8
Pidgeon (2000) 11
Overall assessment and conclusions 14
3 CONCEPTUAL MODELS 15
Conceptual model of disturbances at the plant scale 15
Direct disturbance effects on plants 18
4 SUMMARY AND CONCLUSIONS 27
REFERENCES 29

ILLUSTRATIONS

Figure 1. Soil texture differences between sites 6
Figure 2. Vegetation characteristics of the three sites of the MacKay and Herrick experiment 7
Figure 3. Vegetation types on McGregor Range 13
Figure 4. Conceptual model of disturbance impacts on plants 17
Figure 5. Conceptual model of direct disturbance effects on plants 19
Figure 6. Trial runs of SOILWAT for determining the impact of soil compaction on plant transpiration 24
Figure 7. Effects of wind erosion in an intensive training area on sandy soil at Fort Bliss 25

TABLES

Table 1. Defining characteristics of the disturbance regime at the plant scale. ... 16
Table 2. Different disturbance types and their direct and indirect effects on plants. 18

PREFACE

The Construction Engineering Research Laboratory (CERL) Principal Investigator for this project was Dr. Jeffrey S. Fehmi. The managers at Fort Bliss were Kevin vonFinger and Brett Russell. The work was performed under contract by Debra P.C. Peters and Tamara Hochstrasser in association with New Mexico State University and USDA-ARS Jornada Experimental Range. The technical editor was David Cate, Information Technology Laboratory. Mr. Stephen Hodapp is Chief, CEERD-CN-N, and Dr. John T. Bandy is Chief, CEERD-CN. The associated Technical Director was Dr. William D. Severinghaus, CEERD-CV-T. The Director of CERL is Dr. Alan W. Moore.

This study was conducted for the Office of the Directorate of Environmental Programs (DAIM), Assistant Chief of Staff (Installation Management) (ACS[IM]) under project 622720896, “Environmental Quality Technology,” Work Unit CNN-T081. The technical monitor was Dr. Vic Diersing, DAIM-ED-N.

CERL is an element of the U.S. Army Engineer Research and Development Center (ERDC), U.S. Army Corps of Engineers. The Commander and Executive Director of ERDC is COL John Morris III, EN, and the Director of ERDC is Dr. James R. Houston.

Determining Research Gaps in Disturbance Data for Fort Bliss and a Conceptual Model

TAMARA HOCHSTRASSER, DEBRA P.C. PETERS, AND JEFFREY S. FEHMI

1 INTRODUCTION

The U.S. Department of Defense is responsible for managing over 25 million acres of land and uses a variety of programs to periodically assess land condition.

Numerous research and outside monitoring efforts have been completed for Fort Bliss, Texas. Periodically it is useful to gather the past efforts together and evaluate them as a composite and also ensure their continued availability. The objectives of this research project were to identify research gaps in disturbance data for Fort Bliss and to use the available information to develop conceptual models of disturbances of military lands. This report outlines the results of collaboration among the Jornada Experimental (JER) Range Department at New Mexico State University, the U.S. Army Engineer Research and Development Center (ERDC) Construction Engineering Research Laboratory (CERL), and the Army installation at Fort Bliss.

Over 70% of U.S. military reservations are located in arid lands of the western U.S. With its large spatial extent (1.1 million acres) and arid climate, Fort Bliss offers an excellent site for studying the effects of disturbances on vegetation dynamics. Furthermore, certain areas of Fort Bliss are of prime interest for the preservation of endangered species, such as the Aplomado falcon. In this report, we summarize results from previous experimental studies on military disturbances on Fort Bliss. We used these studies (and others) to develop conceptual models of the impact of military disturbances on vegetation dynamics in arid lands.

2 RESEARCH GAPS

The available data were gathered from some previous experimental work on Fort Bliss. The following section reviews three major research projects on military disturbances at Fort Bliss: MacKay and Herrick (1996), Jones et al. (1997), and the dissertation of Pidgeon (2000).

MacKay and Herrick (1996)

General description of study

The objectives of the study were to evaluate the short-term impacts of wheeled vehicles on vegetation and make predictions of the long term impacts. The secondary objectives were to evaluate the impacts on soil structure and develop a conceptual model.

This experiment was conducted on Otero Mesa (Grazing Units area, by Highway 506). Three 1-km^2 sites were selected. At all sites, five plots of 100 × 200 m were randomly located. Within each plot, there were six transects running from south to north. A different treatment was assigned to each transect: two control treatments (DCC, WCC), five Humvee passes during the dry season (D05), 20 Humvee passes during the dry season (D20), five Humvee passes during the wet season (W05), and 20 Humvee passes during the wet season (W20). Dry season treatments were applied in May 1996 for site 1 and in October 1996 for site 2. Wet season treatments for both sites were applied in July 1996. It was reported that site 1 was wetter during the "wet" season treatment than site 2.[*] Measurements were made immediately after treatment and repeated in May 1997.

Measurements conducted

- Infiltration: only sites 1 and 2, because of rockiness of soil in site 3.
- Bulk density: only sites 1 and 2, because of rockiness of soil in site 3.
- Penetrometer: only sites 1 and 2, because of rockiness of soil in site 3.
- Proctor test (in the laboratory).
- Erosion bridges.
- Soil crust stability (modified Slake test).
- Soil texture.

[*] Personal communication, J. Herrick, USDA-ARS Jornada Experimental Range.

- Soil moisture and temperature.
- Soil carbon analysis.
- Soil nitrogen analysis.
- Pre-treatment vegetation.
- Post-treatment vegetation: apparently measured by B. Russell from Fort Bliss.*
- Weather data at site 1.

Products

- Taylor Soltero, H. (1996) Comparison of field methods and procedures to estimate termite activity in the northern Chihuahuan desert. MS Thesis. University of Texas, El Paso. (Study conducted at the Jornada Experimental Range, funded by EPA).
- Mendoza, V.B., S.H. Watts, R.A. Guerrero, A.M. Hernando, M.P. Perez, M.D. Gaglio, and W.P. MacKay (1997) The impact of wheeled vehicle maneuvering on the flora and fauna of the Chihuahuan desert. Final report. U.S. Army Corps of Engineers Construction Engineering Research Laboratory, Champaign, IL.
- Hernando, A.M. (1999) Effect of military wheeled vehicles on soil compaction in the Chihuahuan desert. M.S. Thesis, University of Texas, El Paso.
- Perez, M.P. (1999) Impact of military wheeled vehicles on water infiltration rates on Chihuahuan Desert soils. M.S. Thesis, University of Texas, El Paso.

Datasets

All of the electronic data are available on the appended CD.

- Infiltration: data set in tables in final report as well as in Perez (1999).
- Bulk density: data set in tables in final report as well as in Hernando (1999).
- Penetrometer: data set in tables in final report as well as in Hernando (1999). Data from 1996 in electronic format (PMTABLE.xls).
- Proctor test: data set in Hernando (1999).
- Erosion bridges: averages reported in final report (Mendoza et al. 1997).

* Personal communication, W. MacKay, New Mexico State University.

- Soil crust stability (modified Slake test): treatment averages in final report (Mendoza et al. 1997). A QuattroPro data file (slake.wb2, slake.xls) containing the 1996 data was also obtained from J. Herrick.
- Soil texture: introduced data on a per-plot basis from Perez (1999) into Excel file (soil-texture.xls).
- Soil moisture and temperature: gravimetric soil moisture; incomplete data set in final report (Mendoza et al. 1997). Monthly averages from automated soil moisture and temperature monitoring at all three sites in final report (Mendoza et al. 1997).
- Soil carbon analysis: data on a per-plot basis in final report (Mendoza et al. 1997).
- Soil nitrogen analysis: data on a per-soil-layer/per-plot basis in final report (Mendoza et al. 1997).
- Pretreatment vegetation: data available (site1.xls, site2a.xls, site2b.xls, site3a.xls, site3b.xls); transformed data into quadrat × species matrix for further analyses. In addition to vegetation data on plots, additional line-intercept and belt transects were read at all three sites. Data from these measurements are available, too (Belts1, Belts 2a,b,c,d,, Belts3a,b,c,d.xls and Lines1a,b,c,d, Lines2a,b,c,d, Lines3a,b,c,d.xls).
- Post-treatment vegetation: apparently measured by B. Russell from Fort Bliss.*

Results

Infiltration

- Site 1: infiltration between active treatments (5 passes or 20 passes) was not different. A difference in infiltration rates and times was observed immediately after the wet pass in July 1996 when infiltration was significantly lower. This effect had disappeared one year after the treatment. No difference between active treatments and controls was observed during the dry season.
- Site 2: no effect of treatments on infiltration was observed. This result may be due to the difference in soil moisture content during the “wet season” between site 1 and site 2.

* Personal communication, W. MacKay, New Mexico State University.

Bulk density

- Site 1: bulk density between active treatments (5 passes or 20 passes) was not different. An increase in bulk density was observed in the second soil layer (5–15 cm), both in the dry and wet season. The effect was larger in the wet season, though.
- Site 2: no effects could be observed. An indication of a trend opposite to the observations at site 1 was observed, with active treatments showing lower bulk density at certain times (Hernando 1999).

Penetrometer. Penetrometer results are difficult to interpret, as very different effects were found. Generally, deeper soil layers seemed to be a little more affected by active treatments (5 or 20 Humvee passes). At both sites in 1996, the number of strikes was significantly higher than for the control in the second soil layer (5–15 cm) when active treatments were applied during the wet season. The first soil layer (0–5 cm) needed a significantly more strikes to penetrate after 20 Humvee passes. These effects persisted in site 1 until 1997. Most treatments during the dry season were not significantly different from the control. However, a significant effect of the treatments could be found in a few soil layers at both sites. At site 2, soil layers that required significantly more strikes in 1996 recovered by 1997. The third soil layer (15–25 cm) in site 1 required significantly fewer strikes under the active treatments when they were applied during the dry season. The same was true for the first layer (0–5 cm) at both sites, when only 5 Humvee passes were applied during the wet season in 1996. In 1997, the effect on the third layer at site 1 had disappeared, whereas the first layer in the wet treatments needed significantly more strikes in 1997. In general, between-plot heterogeneity of the results increased from 1996 to 1997.

Proctor test. This test was conducted by Hernando (1999). The results from the test as reported in the thesis are difficult to interpret. This test can only contribute minor information to the questions asked.

Erosion bridges. No significant differences were found between control and active treatments at all three sites.

Soil crust stability (modified Slake test). All three sites showed a significant loss of soil crust stability immediately after treatment in the first soil layer (0–5 cm) when the treatment occurred in the dry season. No significant differences were observed for wet season treatments. All treatment effects had disappeared after one year.

Soil texture. The main difference in soil texture between the two sites was that site 1 had a much higher clay content in the second soil layer (5–15 cm) (Fig. 1). Some differences in soil texture between plots could be detected. Data are

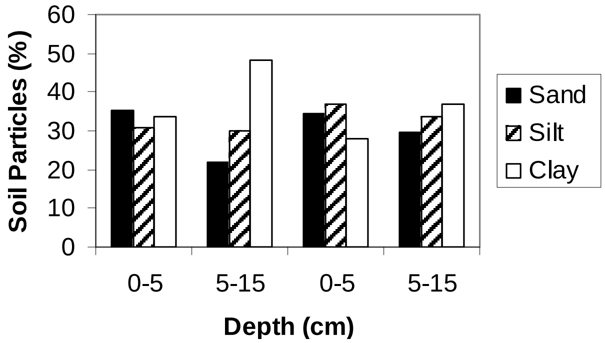

Figure 1. Soil texture differences between sites. [Figure based on Table 2 in Perez (1999).]

available on a per-plot basis, for site 1 for both treatments together, and for site 2 separated by wet and dry season transects (Mendoza et al. 1997). Treatments had no effect on soil texture.

Soil moisture and temperature. Gravimetric soil moisture data were collected to confirm that treatments were applied at the right season. Between-plot variability and variation by depth were detected. The data presented in the final report are incomplete in that there is no indication as to when the measurements were made and where the measurements from other seasons are located (Mendoza et al. 1997).

In addition, soil moisture was monitored using permanently installed gypsum blocks at all three sites. Soil temperature was also monitored using permanently installed sensors. Monthly averages from these measurements are reported (Mendoza et al. 1997). Measurements started in July 1996 at sites 1 and 2 and in November 1996 at site 3. All measurements were ended in September 1997.

Soil carbon analysis. No significant differences were found between soil carbon contents of treatments and controls. There was a very high plot-to-plot variability in treatment effects.

Soil nitrogen analysis. No significant differences were found between soil nitrogen contents of treatments. Contrary to soil carbon content, there also does not seem to be a significant plot effect.

Pretreatment vegetation. Cover was higher in sites 2 and 3 than in site 1 (Fig. 2a). Total species richness was highest in site 3 (Fig. 2b).

Weather data. Air temperature, relative humidity, wind direction, wind speed, and rainfall were recorded between July 1996 and September 1997 at site 1. Monthly averages are reported.

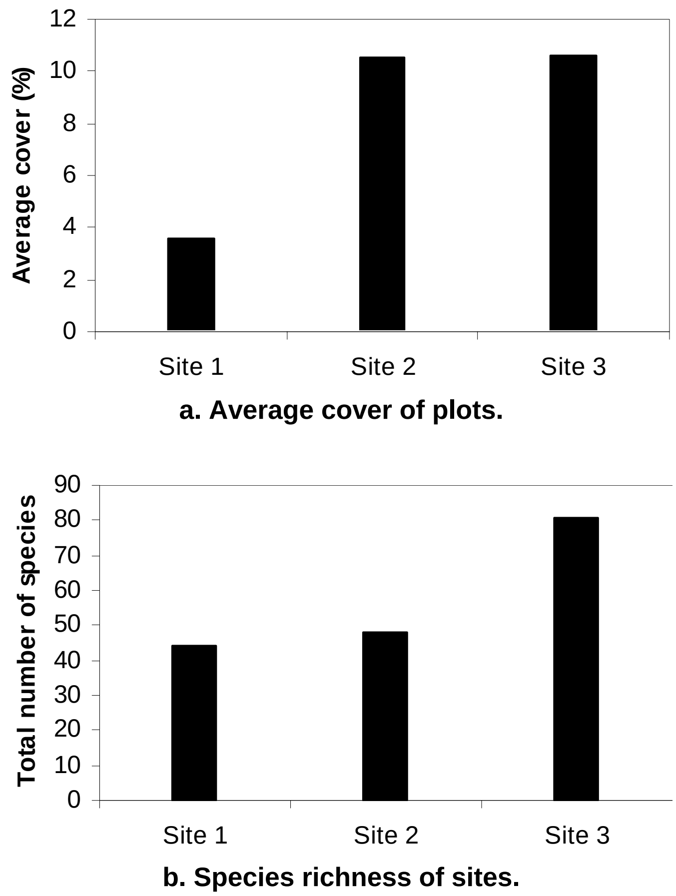

Figure 2. Vegetation characteristics of the three sites of the MacKay and Herrick experiment, based on pretreatment data.

Limitations

Replication in this study was insufficient, especially for wet treatments, since the two sites at which important differences in soil characteristics were measured often showed opposite results. Data on post-treatment vegetation are missing (measurements were apparently made by Fort Bliss), and soil texture data for site 1 for the dry season are not available. More soil moisture data may also exist, as soil moisture should have been measured in parallel with measurements using the penetrometer. With these data gaps, this data set is of limited use on its own. However, the limited information on disturbance effects on soils contributes to our understanding of military disturbances.

Simulated track maneuver study (Jones et al. 1997)

General description of study

The objective of this project was to conduct basic research on the impact of tracked-vehicle disturbance on soils vegetation and hydrology that supports the development of day-to-day management strategies. This effort is directly supportive of the site management plan and represents the application of the research to management.

Soil analysis was conducted at six sites on McGregor Range by New Mexico State University staff. Four sites were selected for an experiment using tracked and wheeled vehicles. They were chosen to represent two sites with deep soil, no slope, and shrub- or mixed-dominated vegetation (Pendejo Wash #1 and #2) and two sites with shallow soils, slopes, and grass-dominated vegetation (Philder site #4, Campbell tank #5). Site 4 was located on Otero Mesa (Maneuver Area 18), and site 5 was located southwest of the Otero Mesa rim near Campbell Tank (Maneuver Area 26). At each site, two areas were chosen as replicates.

Treatments

Pass x season treatments at sites 4 and 5 (Fuchs 1997) and presumably sites 1 and 2.

- Untreated control.
- One pass by a wheeled vehicle in June 1994.
- Ten passes by a wheeled vehicle in June 1994.

Additional pass x season treatments at site 5

- One pass by a tracked vehicle in October 1994 (wet soil conditions).
- Three passes by a tracked vehicle in October 1994 (wet soil conditions).
- One pass by a tracked vehicle in April 1995 (dry conditions).
- Three passes by a tracked vehicle in April 1995 (dry conditions).

Site descriptions

Sites 1 and 2 (Pendejo Wash). Soils at site 2 had significantly less gravel than at site 1 and were somewhat finer textured (loam instead of sandy loam).

Sites 4 and 5. The slope at site 4 (Philder site) was about 0 to 9 percent, whereas it ranged from 5 to 20 percent at site 5 (Campbell tank). Site 5 receives runoff from the limestone outcrop above the site. The soil at site 4 had a very fine sandy loam surface layer, approximately 10 cm thick, and a subsoil that was

about 20 cm thick. The upper part of the subsoil is sandy clay loam, and the lower part is gravelly sandy clay loam and contains about 30 percent indurated caliche fragments. An indurated caliche layer occurs at a depth of less than 50 cm. In contrast, the soil at site 5 had a rocky surface layer (very gravelly loam) about 18 cm deep. The subsurface layer varies from a very gravelly loam to very gravelly silty clay loam about 20 cm thick. Unweathered limestone bedrock is at a depth of about 38 cm. Site 4 was dominated by black grama (60% composition), blue grama (5% composition), and bush muhly (5% composition), whereas site 5 was dominated by black grama (30% composition), gyp grama (15% composition), and slim tridens (5% composition).

Measurements conducted

- Soil description (six sites).
- Rainfall.
- Sediment yield from runoff (four plots on each treatment) (sites 4 and 5).
- Soil surface microtopography (sites 4 and 5).
- Basal vegetation cover (sites 4 and 5).
- Soil moisture (neutron probe) (sites 1, 2, 4, and 5).
- Bulk density (neutron probe) (sites 1, 2, 4, and 5).
- Microrelief.
- Soil erosion.
- Runoff volume.
- Weather data (hourly, weather stations at sites 1, 4, and 5).

Products

- Fuchs, E.H (1997) Sediment removal by water following mechanical surface disturbance on Chihuahuan desert soils in New Mexico. M.S. Thesis, New Mexico State University, Las Cruces.
- Montes-Helu, M.C. (1997) Track-vehicle disturbance on rangeland and design of sap flow gauge for desert shrubs. Ph.D. Dissertation, New Mexico State University, Las Cruces.

Data sets

All data sets from Montes-Helu are gathered on the appended CD. Data sets with no data file indicated are not available.

- Rainfall.
- Sediment yield from runoff (four plots on each treatment).
- Soil surface microtopography.
- Basal vegetation cover.
- Soil moisture (neutron probe): raw data from surface neutron probe (snp_cnts.txt) and downwell neutron probe (dwp_cnts.txt) available in Montes-Helu (1997).
- Bulk density (neutron probe): raw data available in Montes-Helu (1997) (ini_den.txt).
- Mircorelief: profile measurements after dry treatments; raw data (prof_dat.txt) available in Montes-Helu (1997).
- Soil erosion.
- Runoff volume: raw data in Montes-Helu (1997) (runoff.txt).
- Weather data: daily summaries (from hourly data) available in Montes-Helu (1997) (wth_monthly.txt). We cleaned up these data and identified missing values (wth_monthly.xls).

Results

Sediment yield from runoff (four plots on each treatment). Sediment yield from runoff usually peaked a few days after precipitation events. The sediment loss from control plots was not significantly different from sediment loss from treatment plots with one pass, both after the wet and the dry season treatments. Ten passes of a Humvee increased sediment loss from the plot in the first year after treatment; after one year, sediment loss was similar to control plots. Rather than being able to explain sediment loss with treatments, a high inverse correlation of sediment loss with vegetation cover was observed.

Bulk density (neutron probe). With one or five passes of tanks, bulk density did not seem to increase more than is observed within the range of natural variation in bulk density over time. Bulk density ranged between 1.2 and 1.6 at all sites.

Microrelief (profile of tank tracks). The soil surface was lowered by several centimeters under the tank tracks. With more than one pass, often the width of the track was increased as well as the depth. After eight months the tracks were still visible at many sites.

Soil erosion. Soil erosion results from the sites were inconclusive. Even though there was net soil movement at all sites, there was no clear pattern of erosion and deposition between treatments.

Water balance. The destruction of the vegetation in tank tracks led to an increase in water storage in the soil in some treatments because of the reduction in transpiration.

Limitations

The description of treatments is unclear; it is different in Montes-Helu (1997) and Fuchs (1997). The microtopography measurements are useful for understanding small-scale soil movement and the effects of disturbances on erosion. Technical reports for this study have not been located; they may be lacking because of illness of the principal investigator when the study was completed.*

The original weather data files are missing. Relative humidity is not summarized in the existing data file (daily summary). Potentially, soil moisture data (from gypsum blocks at weather stations) should also be available.

Pidgeon (2000)

General description of study

A survey of avian abundance and nesting success was conducted over three years (1996–1998), and vegetation was characterized. Avian abundance and nesting success were related to vegetation characteristics. To assess vegetation change between the 1880s and the present, U.S. General Land Office territorial survey records were used to reconstruct vegetation cover in the 1880s. Vegetation change over the past century may be related to changes in bird communities, since birds are sensitive to vegetation characteristics.

Sampling design

Six plots of 1200 × 900 m (108 ha) were selected in four shrubland types (mesquite, creosote, sandsage, and whitethorn acacia) and one grassland type (black grama) such that there was a 50-m buffer of habitat around each plot. Sampling plots were located using a 300- × 300-m grid in each 108-ha plot. At each grid point, five sampling plots were used to estimate ground cover of seven cover categories (cactus, forb, grass, bare ground, litter, shrub, and cholla), three

---

* Personal communication with J. Herrick, USDA-ARS Jornada Experimental Range.

sampling points were used to estimate shrub density of five categories (short shrubs, tall sparse shrubs, tall dense shrubs, yucca species, and total shrubs), and four sampling points were used to estimate foliage height diversity. Avian abundance was estimated using point counts at each grid point that were repeated four to five times each year. In addition, nest counts were made every year, and nesting success was determined in all of the five vegetation types, an additional grassland type (mesa grassland), and piñyon-juniper woodlands.

Measurements conducted

- Vegetation characteristics, completed once over the three years of study.
- Historic vegetation descriptions from the 1880s.
- Avian abundance, measured each year.
- Nest counts and nesting success estimates.

Products

- Pidgeon, A.M. (2000) Avian abundance and productivity at the landscape scale in the northern Chihuahuan desert. Ph.D. dissertation, University of Wisconsin, Madison.
- Pidgeon, A.M., N.E. Mathews, R. Benoit, and E.V. Nordheim (2001) Response of avian communities to historic habitat change in the northern Chihuahuan desert. *Conservation Biology*, **15**(6): 1772–1788.

Data sets

No data sets were available in electronic format. Means and standard deviations for vegetation characteristics and data on birds are in the dissertation.

Results

Results from bird observations are not summarized here, since these are irrelevant to our project. Figure 3 shows the distribution of vegetation types in the study area on McGregor Range.

Black grama grassland. Grass cover was predominant, both in the 1880s and 1990s. The average grass cover was 40%.

Whitethorn acacia shrubland. There was a high average density of shrubs ($0.25/m^2$); the average grass cover was 14%. This vegetation type also did not seem to have changed much over time.

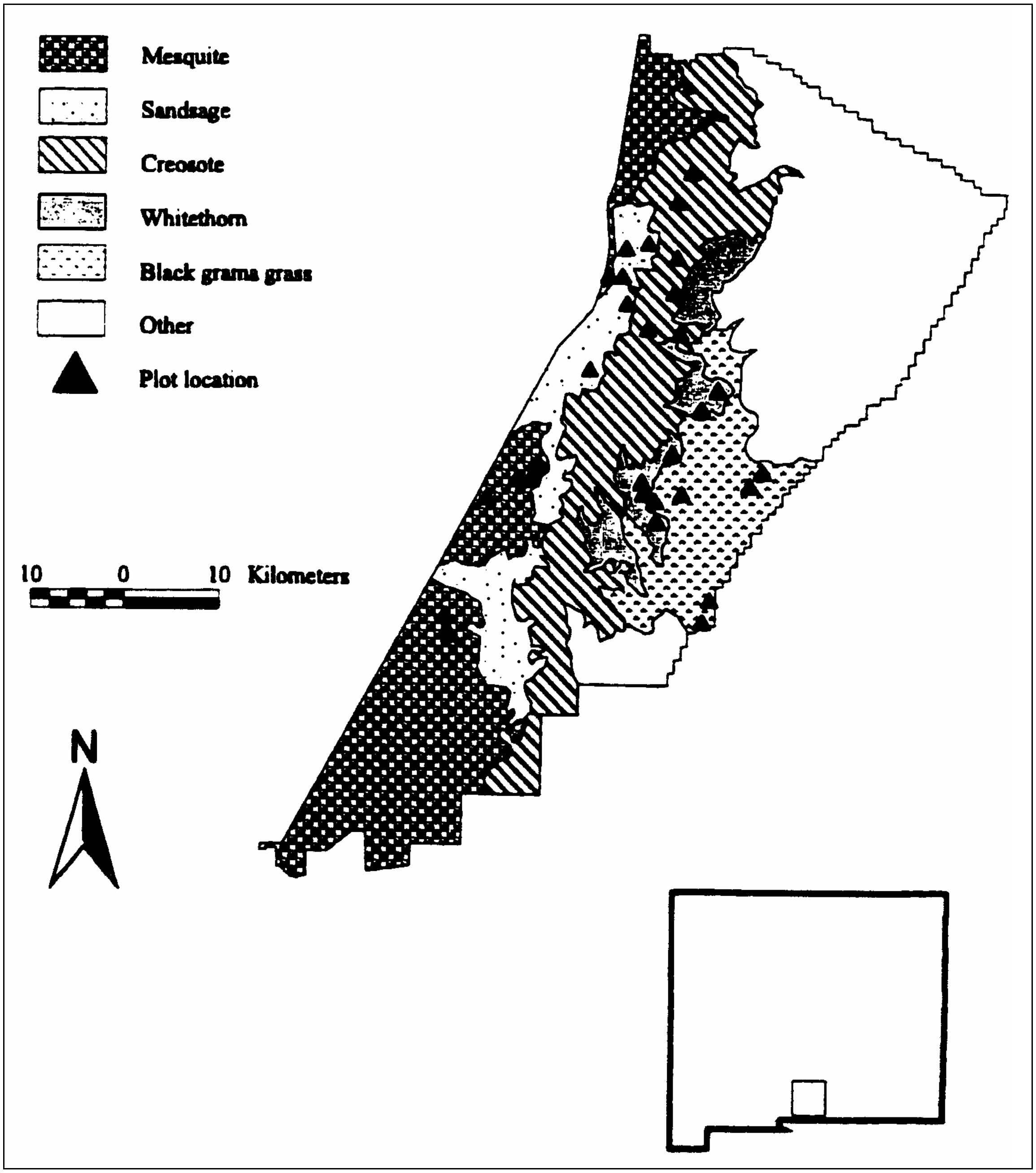

Figure 3. Vegetation types on McGregor Range as described in Pidgeon (2000).

Creosote shrubland. Few shrubs and high grass cover were present on most plots in 1880s; now the shrub density is $0.26/m^2$ and the grass cover is 12%.

Sandsage shrubland. The forb and litter cover was high, the grass cover was 17%, and the shrub density was moderately low ($0.16/m^2$). Little is know about the past of this vegetation type.

Mesquite shrubland. A substantial change in the heights of shrubs and the heights of “hummocks” as well as a loss of grasses could be observed over time.

Limitations

The results from this study seem to be in GIS coverages. The historical vegetation descriptions and the match with current vegetation surveys are valuable for evaluating vegetation change over time. It would be interesting to be able to obtain those data. The avian survey seems to be extensive and is pertinent to questions of bird conservation.

Overall assessment and conclusions

The experimental work on military disturbances conducted at Fort Bliss was usually associated with intensive sampling. However, the treatments were often not well replicated, which in some cases contributed to inconclusive results from these studies. Furthermore, the studies were generally not long enough for the full impact of the disturbances to be measured. In particular, erosional processes that may only start a few years after the original disturbance occurred were not observed in these studies. These long-term impacts are important in evaluating the impact of military disturbances and estimating the recovery times from military disturbances. Therefore, we recommend revisiting these experimental sites and gathering information on the differences between treatments.

Appropriate data archiving and accessibility to historical data are unresolved issues for long-term ecological research. Similar to other sites, Fort Bliss data management and accessibility could be improved. Even though a great variety of ecological parameters were measured for each military disturbance experiment, the data are not well documented and are difficult to use for people who were not involved with the projects. For example, a detailed description of the vehicle used to conduct the experiments and speed at which it was driven is often lacking from the meta-data. Furthermore, Fort Bliss potentially has an extensive library of spatial data, including vegetation, soils, and elevation. It would be beneficial if those data were made more readily available to researchers. This would stimulate research on scales that are more relevant for management decisions.

3 CONCEPTUAL MODELS

The second goal of this project was to develop a conceptual framework describing the impacts of military disturbance on vegetation and soils, including definiting management goals, specifying details and scale of data and modeling needs, and developing monitoring approaches.

The conceptual framework of disturbances developed in this research is the first step toward developing simulation models. Since the response of individual plants to disturbances is crucial for mechanistically explaining vegetation dynamics after disturbances, the individual plant was the focus for the development of our conceptual framework. After presenting a general framework of disturbances at the plant scale, we will present how direct and indirect effects on plants influence the recovery of vegetation from disturbances.

Conceptual model of disturbances at the plant scale

"Disturbance" is a term that is used in many different contexts and with equally many meanings. A definition of what we understand by disturbance is therefore warranted. Following the work of many disturbance ecologists, we are using the definition first provided by White and Pickett (1985, p.7): "A disturbance is any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment." This general definition leaves matters of scale and processes to be defined in each case. Our focus was on the individual plant scale, and we were interested in direct and indirect effects of disturbances on plants. This is different from most disturbance studies, which tend to focus on the plant community or the landscape scale.

A single disturbance is part of a "disturbance regime," which is the ensemble of all disturbance events of the same type that occur within the same system. The characteristics of disturbance regimes at the plant scale are summarized in Table 1, based on more general definitions of these characteristics. Some characteristics of a disturbance regime pertain to the description of the disturbance itself, others to the description of its impact on the system (the plant or the soil). In addition to White and Pickett (1985), we included a description of the cumulative effect of the disturbance regime on the system, which depends both on the system and the disturbance (long-term effect). For the simulation of disturbance regimes, the distinction between characteristics of the disturbance regime that depend on the system and the ones that depend on the disturbance type is very important. Separate conceptual frameworks are needed for incorporating the effects of

disturbances that depend on the disturbance type and the ones dependent on the system into simulation models. In what follows we are mainly going to develop a conceptual framework for the disturbance effects that depend on the system, such as the percentage of biomass impacted, etc. (Table 1). The characteristics of the disturbance regime that are dependent on the disturbance type are going to be input parameters provided by the user of the simulation model. This is appropriate for human disturbances since the disturbances regime is dictated by management decisions.

Table 1. Defining characteristics of the disturbance regime at the plant scale.

Characteristic	General meaning (White and Pickett 1985)	Plant scale	Disturbance type/ System characteristic?
Distribution	Spatial distribution	Plant species and plant organ affected	Disturbance type
Overlap	Likelihood of a disturbance event affecting the same spot as a previous disturbance	Likelihood of a disturbance event affecting the same plant	Disturbance type
Frequency	Mean number of events per time period	Same	Disturbance type
Return interval	The inverse of frequency	Same	Disturbance type
Predictability	A scaled inverse function of variance in the return interval	Same	Disturbance type
Intensity	Physical forces of the event per area per time	Same	Disturbance type
Severity	Impact on the organism, community, or ecosystem	Impact on plant	System
Area or size	Area disturbed (percentage of total available area)	Percent of biomass removed	System
Rotation period	Mean time needed to disturb an area equivalent to the study area	Not applicable	System
Synergism	Effects on the occurrence of other disturbances	This will only be implicitly addressed	System
Long-term effect of disturbance	Cumulative effect of disturbance on system	Disturbance return interval: Time of recovery	System and Disturbance type

However, the characteristics of the disturbance regime that depend on disturbance type are mostly known at the landscape scale. Therefore, a translation from the landscape-scale description of the disturbance regime to the plant scale is required (Fig. 4). In particular, the probability that a plant is affected by a disturbance event has to be derived from the landscape-level user

input (probability of occurrence). Second, the impact on the plant/soil depends on disturbance intensity and the current state of the plant and soil (i.e. disturbance severity). The severity of disturbance, as well as the rate and length of the recovery process, determine in what state the plant/soil is when the next disturbance event occurs (Fig. 4). The severity of the disturbance can depend both on the number of processes it impacts and on the intensity with which these processes are impacted. Which processes are impacted and how much depends on the disturbance type (Table 2).

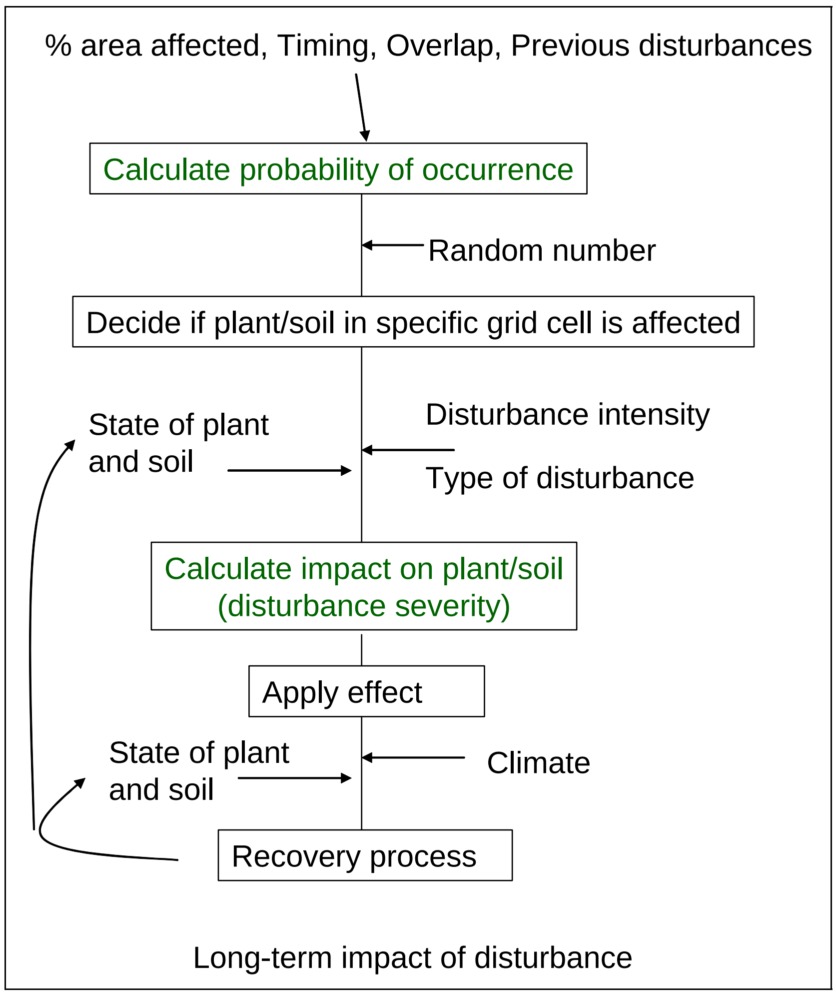

Figure 4. Conceptual model of disturbance impacts on plants.

Table 2. Different disturbance types and their direct and indirect effects on plants.

Type	Site		Effect on plant				
	JER	Fort Bliss	Mortality	Biomass removal	Litter removal	Reproduction	Soil
Grazing	X	X	No	30% of above-ground biomass of grasses	No	Reduction of grass seed production Increase in seed dispersal of mesquite	Some soil compaction Change in surface properties
Shrub removal	X	–	Shrubs only	100% of above-ground shrub biomass	No	Seed production of shrubs impeded	Change in surface properties Compaction (if heavy machinery used)
Wind	X	X	No	No	Yes	Seed dispersal	Soil surface erosion
Fire	X	X	Mostly not	100% of above-ground biomass	100%	Reduction of seed production May impact soil seedbank	Increased nutrient availability Increased erosion?
Trampling	X	X	No	No	No	No	Change in surface properties
Off-road vehicles	X	X	No	Some	No	No	Soil compaction Change in surface properties
Tanks	–	X	Dependent on species	Injuries to roots and stems; Some	No	No	Soil compaction Change in surface properties
Bombs	–	X	Yes	Yes (burnt)	No	Soil seed bank?	Soil compaction Change in surface properties

Direct disturbance effects on plants

The severity of direct disturbance effects on plants depends on a number of factors that can be conceptualized as “filters” of the disturbance intensity (McIntyre and Lavorel 1994) (Fig. 5). Two filters pertain to the timing of the disturbance event. To determine the amount of impact that a disturbance event of a given intensity has on the plant, it is important to determine if the event occurred under wet or dry conditions. Furthermore, the phenological stage of the plant at the time of the disturbance event changes the disturbance severity. A third filter pertains to species characteristics of a plant: the growth rate and allocation pattern, recruitment characteristics, and

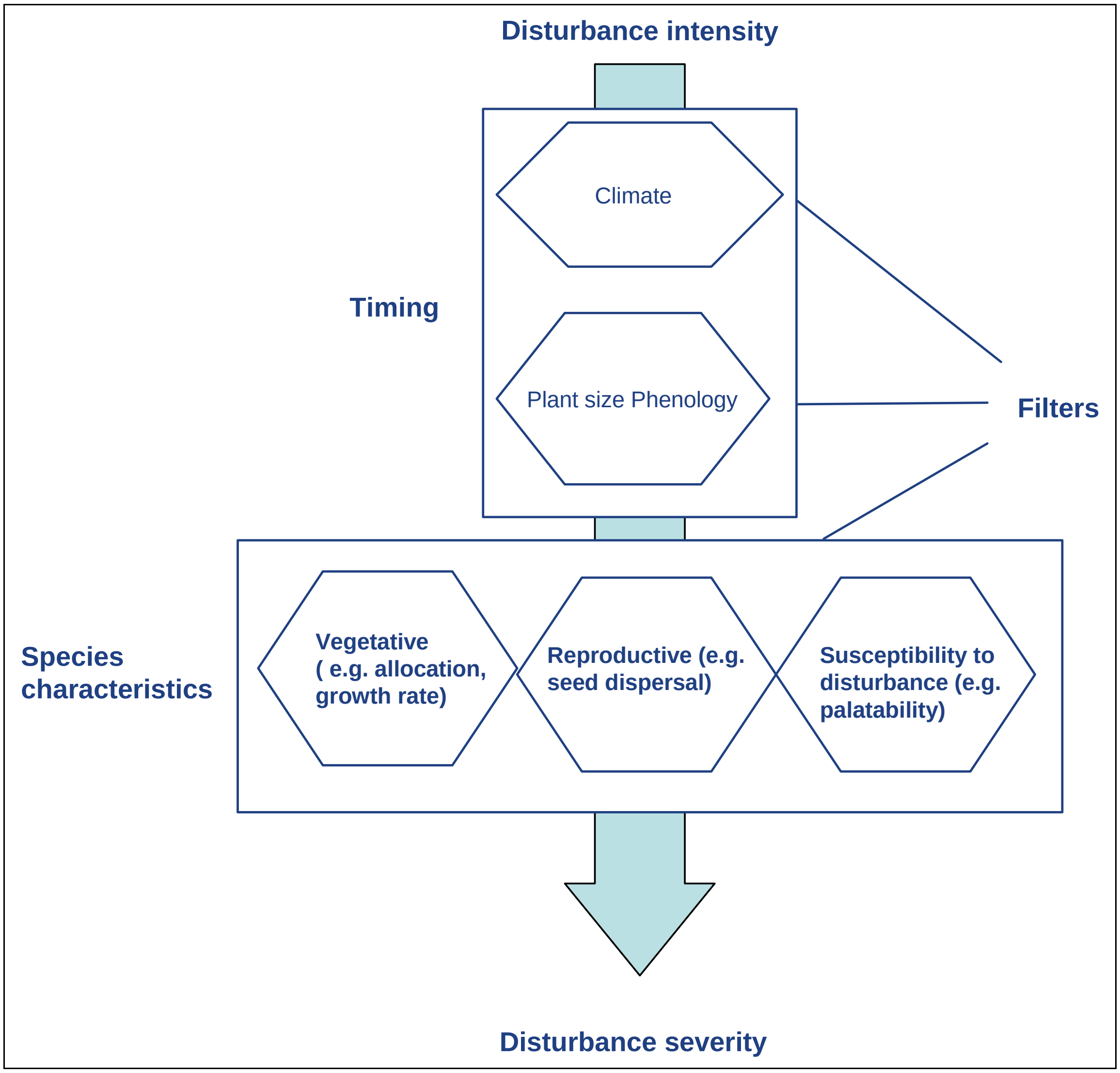

Figure 5. Conceptual model of direct disturbance effects on plants. The disturbance intensity is "filtered" by the timing of the disturbance with respect to the timing of the disturbance and species characteristics.

characteristics that increase the probability that the vegetative/reproductive parts are impacted by a disturbance (e.g. the palatability of a species, the position of meristems) (Fig. 5). Differences in these characteristics between species can result in differences in the amount of tissue damaged (resistance), in regrowth (resilience), and in recruitment (resilience). Under frequent disturbances, resistance may be a more important characteristic of plants than resilience,

because resilient plants may not fully recover in intervals between disturbance events (Sun and Liddle 1991). The combination of the timing of the disturbance and the species characteristics will determine the disturbance severity given a certain intensity.

Community-level effects of trampling and off-road vehicle disturbances

The effect of trampling and off-road vehicle disturbances has mostly been measured at the plant community level. The community-level response is relevant to our conceptual framework because the effects on each plant in the community add up to the community-level response. However, when extrapolating from the plant to the community level, one needs to bear in mind that the community-level response includes both the effects of the disturbance on individual plants and plant–plant interactions that may have been modified by the disturbance (Milchunas et al. 2000).

Generally, a loss of vegetation cover and litter is observed with recreational or military use of an area (Trumbull et al. 1994, Whitecotton et al. 2000). However, annual species in Kuwait exhibited higher density and diversity in tracks than in intertrack areas, presumably because water relations were improved in tracks (Brown and Schoknecht 2001). Improved water relations with compacted soil were also found in the Sonoran Desert (Kade and Warren 2002). However, generally recovery from disturbances in desert environments is slow, especially for long-lived perennial plants (e.g. creosotebush) (Prose et al. 1987, Lovich and Bainbridge 1999, Kade and Warren 2002).

Disturbance effects on the cover of the vegetation vary nonlinearly with the disturbance intensity: i.e. the first few passes of a vehicle or a person have a much stronger impact on the vegetation than additional passes. Several attempts have been made to describe this relationship by a logistic or an exponential model where the “steepness” of the increase in damage with increasing disturbance intensity is linearly related to the plant productivity.

When trying to establish how vegetation is affected by disturbance, it is difficult to distinguish the disturbance effects from effects of climatic variation and other factors. It is therefore recommended to look at *relative vegetation cover* (RVC) (Cole 1995a):

$$RVC = \frac{\text{surviving cover on trampled subplots}}{\text{initial cover on trampled subplots}} \times \frac{\text{initial cover on control subplots}}{\text{surviving cover on control subplots}} \times 100 .$$

In a standardized study of the effects of trampling on 18 plant community types (mostly forests and grasslands above timberline), it was found that the loss of relative vegetation cover (RVC) is related to the disturbance intensity according to a second-order polynomial (Cole 1995a):

$$RVC = A - BX + CX^2$$

where A = constant (between 94 and 104)

B = constant (between 0.04 and 0.54)

C = constant (between 0.00004 and 0.00073)

X = trampling intensity.

Plant-scale effects of trampling and off-road vehicle disturbances

Plant age/size. It has long been observed that disturbance effects at any given level of disturbance intensity depend on plant size. Small plants are more affected by disturbance than big ones (Wilshire 1983, Sun 1990, Drewa 2003). Both resistance **and** resilience (regrowth) depend on plant size.

Plant morphology. Plant morphology is important in determining both resistance and resilience to disturbance (Cole 1995b, Yorks et al. 1997). Resistance is primarily a function of lifeform and the erectness of plants (Cole 1995b). Resilience is mostly related to the woodiness of plants (cf. relation of disturbance effect with growth rate) and the location of growing points. If perennating buds are located at or below the soil surface, then recovery after disturbance is faster (Cole 1995b). In another survey, it was found that graminoids had both a high resistance and a high resilience to trampling impacts (Yorks et al. 1997). However, under regular military training in a semi-arid environment, grasslands showed a decline in basal cover, even though they exhibited a relatively high resilience (Milchunas et al. 2000). Disturbance led to an increase in exotic and weedy species.

Growth rate. Growth rate is related to time of recovery from disturbance (resilience). Plants with high growth rates recover more quickly (Sun 1992). Resistance to trampling is not directly linked to growth rate, but plants that are resistant to trampling tend to have a lower growth rate than plants that are not.

Reproductive potential and capability to resprout. The reproductive potential and the capability of plants to resprout are very important in determining plant resilience to disturbances. Very few investigations of plant seedling establishment in trampled areas have been published. However, it was suggested

that monocotyledons may be particularly capable of germinating through a compacted soil surface (Brown and Schoknecht 2001). Since creosote seedlings are susceptible to anaerobic conditions during germination (Valentine and Gerard 1969, Lunt et al. 1973), creosotebush may not be able to establish on compacted soils.

Indirect disturbance effects on plants

Indirect effects that are of particular concern with vehicular traffic are disturbances effects on soils, in particular soil compaction (Webb 1983). Compaction destroys the soil structure, which reduces the amount of macropores in the soil and increases the amount of intermediate-sized pores (Hillel 1980).

The effects of soil compaction on plants were summarized by Kozlowski (1999): “Compaction typically alters soil structure and hydrology by increasing soil bulk density; breaking down soil aggregates; decreasing soil porosity, aeration and infiltration capacity; and by increasing soil strength, water runoff and soil erosion. Appreciable compaction of soil leads to physiological dysfunctions in plants. Often, but not always, reduced water absorption and leaf water deficits develop. Soil compaction also induces changes in the amounts and balances of growth hormones in plants, especially increases in abscisic acid and ethylene. Absorption of the major mineral nutrients is reduced by compaction of both surface soils and subsoils. The rate of photosynthesis of plants growing in very compacted soil is decreased by both stomatal and non-stomatal inhibition. Total photosynthesis is reduced as a result of smaller leaf areas. As soils become increasingly compacted respiration of roots shifts toward an anaerobic state. Severe soil compaction adversely influences regeneration of forest stands by inhibiting seed germination and growth of seedlings, and by inducing seedling mortality. Growth of woody plants beyond the seedling stage and yields of harvestable plant products also are greatly decreased by soil compaction because of the combined effects of high soil strength, decreased infiltration of water and poor soil aeration, all of which lead to a decreased supply of physiological growth requirements at meristematic sites.” In addition to the different distribution in time and space of the plant-available water, a compaction layer can act as an impediment to roots.

Amount of soil compaction with different trampling and off-road vehicle disturbances

Surface loading of soil results in normal and shear stresses that compress and deform soils to increase soil density (Webb 1983). The density of the soil increases as the magnitude of normal and shear stresses increases above the

strength of the soil to resist deformation. The relationship between the application of stress and change in bulk density is nonlinear. An equation that relates applied stress to changes in bulk density has been developed (Assouline 2002).

Changes in soil water dynamics

The reduction of structure in the soil results in increased bulk density (Webb 1983) with two effects on water dynamics: changes in water retention characteristics of the soil and changes in infiltration characteristics. Because soil structure affects the moisture retention characteristics of soil in the low suction range, increased bulk density affects soil moisture content at low water potential. The effect of soil compaction on infiltration is more complicated and not fully understood. It depends on rainfall intensity as well as on soil structure.

To test if soil compaction effects on water retention characteristics are important in our systems, we used the soil water model (SOILWAT) (Parton 1978) linked to ECOTONE (Peters 2002). Since SOILWAT does not currently use bulk density as an input parameter, we needed to find a way to make model results sensitive to bulk density. For this purpose, we changed the water retention curve used in SOILWAT to the van Genuchten equation. The parameters for this retention curve are calculated by the program ROSETTA (http://www.ussl.ars.usda.gov/models/rosetta/rosetta.HTM) based on soil texture and bulk density (Rosetta documentation). Parameters for the van Genuchten equation were then input into the modified version of SOILWAT to conduct preliminary tests as to how soil compaction would affect plant transpiration (an input parameter for ECOTONE). We found that the overall rate of transpiration was not affected by soil compaction. However, there were slight differences in the seasonal distribution of transpiration (Fig. 6) and the soil depths from where the water was lost by transpiration (not shown). The change in bulk density implemented in these runs was large (from BD = 1.4 to BD=2), yet the observed changes in transpiration were small. We therefore decided not to further pursue the implementation of the effect of compaction on water dynamics in ECOTONE. The effects of soil compaction on transpiration may have been stronger had we incorporated the compaction effects on water infiltration. However, this is an area of current research, and the complexity of the processes involved was beyond the scope of this study.

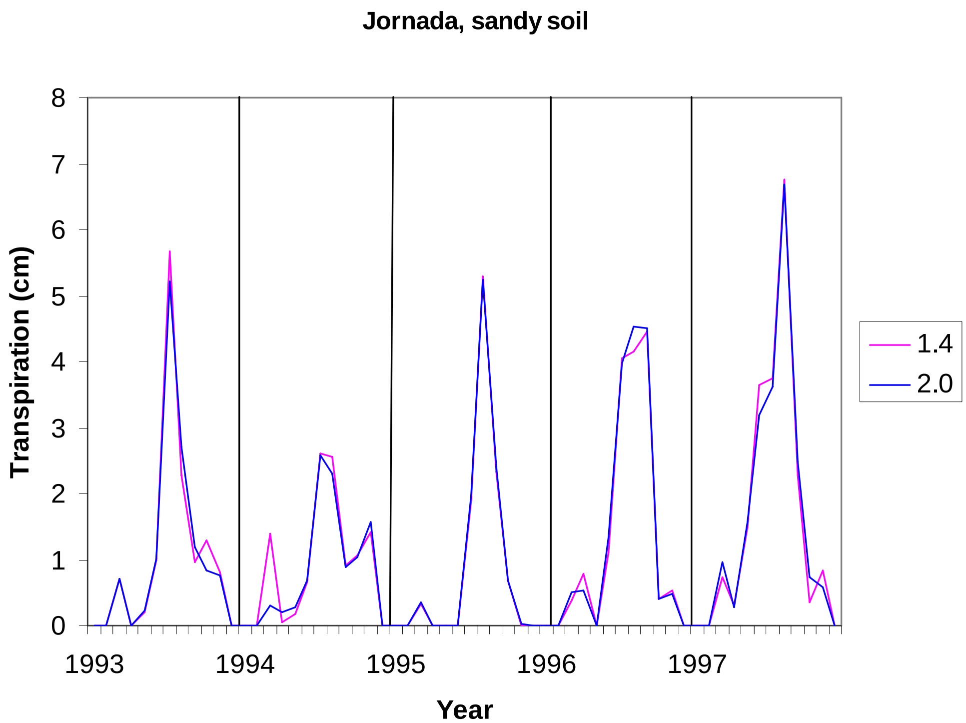

Figure 6. Trial runs of SOILWAT for determining the impact of soil compaction on plant transpiration. A strong difference in bulk density only led to a slight change in the seasonal distribution of the transpiration on a sandy soil.

Wind erosion

If the disturbance intensity is too high or the frequency is such that soil and vegetation cannot recover between disturbance events, then severe degradation of ecosystems can result. During a visit to Fort Bliss, we were shown areas located on sandy soils where intensive military training had taken place. These areas suffered from massive wind erosion of the topsoil, creating both areas of soil depletion as well as areas of soil accumulation. This led to either the formation of plant pedestals or the burial of plants (Fig. 7). The amount of wind erosion appeared to be related to the size of the area impacted by military training, but there is very little understanding as to how much military training can be conducted before erosion can be observed.

Figure 7. Effects of wind erosion in an intensive training area on sandy soil at Fort Bliss

Wind erosion depends on vegetation type and soil surface characteristics (Musick and Gillette 1990, Stockon and Gillette 1990). Drought or conversion from desert grasslands to mesquite dunelands can greatly enhance wind erosion. Grasslands during drought had the highest erosion rate (101 t/ha/yr), whereas mesquite dunes were eroded at a rate of 69 t/ha/yr. The lowest erosion occurred in grasslands during non-drought conditions (40–45 t/ha/yr) (Gibbens et al. 1983). In general, a decrease in vegetation cover can increase wind erosion.

Soils are more prone to wind erosion when the surface is disturbed (Gillette et al. 1980). The impact of disturbances on the susceptibility of the surface soil to wind erosion depends also on soil surface texture and soil moisture content (Gillette and Adams 1983). Sandy soils require lower threshold velocities for wind erosion to occur. However, for the management of disturbance effects on wind erosion, it is most important to know on what soil types the change in wind erosion with disturbance is smallest. The smallest changes in wind erosion occur on very fine and very coarse-textured soils because of the high threshold velocities of fine-textured soil (e.g. playa) and the low threshold velocities of coarse-textured soil (e.g. sand dunes) (Gillette and Adams 1983). A calculation of the importance of wind erosion in different soil types was presented in Gillette and Adams (1983). A more detailed model is now being developed at the Jornada Experimental Range and will become part of ECOTONE in the future.

4 SUMMARY AND CONCLUSIONS

The most important finding resulting from this research is that disturbance effects can depend on numerous factors linked to both the characteristics of the disturbance type and the system impacted. Therefore, when conducting a disturbance experiment, it is important to keep a good record of both disturbance and system properties. The complex effects of military disturbances result from changes in a multitude of ecosystem processes, which makes it difficult to interpret experimental results. In future research it may be beneficial to work with simplified systems, e.g. to apply uniform pressure to the plant and soil (rather than using a vehicle that does not apply pressure uniformly throughout its track). Such simplified experiments could complement full-scale field experiments and help in understanding them.

A major research gap in the research on military disturbances is the lack of information on plant-scale impacts of the disturbances. At Fort Bliss, all of the observations were made at the plant community level, and little is known about the fate of individual plants under the disturbance. Even searching the literature more widely, we could not find adequate information on how individual plants react to disturbances. Not enough is known about the ecology of the dominant and subdominant plants at Fort Bliss to determine from the literature the responses of these plants to disturbance. However, an understanding of disturbance effects at the plant scale is essential for developing a mechanistic understanding of military disturbances at Fort Bliss. The conceptual models that we built and the literature reviews we conducted during this research project will, we hope, inspire experiments on Fort Bliss that are more closely targeted towards particular processes at the plant scale.

Apart from inspiring field experiments, the conceptual framework developed here is of use for the development of the vegetation simulation model ECOTONE. Since ECOTONE is already simulating vegetation dynamics based on the fate of individual plants, it is appropriate to use this model to gain insights into the mechanisms leading to vegetation change under military disturbances. However, to develop management recommendations for the landscape scale, a number of intermediate-scale studies are also necessary, since results from the plant scale cannot be linearly extrapolated to the landscape scale. The Jornada Experimental Range has plans to develop a modeling framework for the landscape scale that would allow scaling up of plant-level vegetation dynamics. It is essential to take processes above the plant level into account when it comes to predicting disturbance effects at the landscape scale.

Structural characteristics of the ecosystem may greatly affect the recovery of the vegetation after disturbances. For example, variations in soil texture, landscape position, and plant species composition may create strong differences in the susceptibility of the vegetation to disturbances. When selecting replicates for experiments on disturbances and/or monitoring purposes, it is therefore important to take these differences between sites into account and select enough sites from one soil and vegetation type. Structural characteristics of the ecosystem are also good indicators of ecosystem health and can be used for monitoring recovery from disturbance (Herrick et al. 2005).

Military disturbances affect ecosystems on multiple scales. Therefore, it is important to monitor the effects of disturbances at multiple scales ranging from the plant and microtopography to the landscape scale. Where multiple disturbances occur (such as grazing and military disturbance), the additive effects of these disturbances have to be monitored carefully. It is advantageous to have a conceptual framework in mind as to how these disturbances interact. Furthermore, long-term observations will contribute to our understanding of disturbances and may help resolve some of the discrepancies observed in short-term experiments.

REFERENCES

Assouline, S. (2002) Modeling soil compaction under uniaxial compression. *Soil Science Society of America Journal*, **66**(6): 1784–1787.

Brown, G., and N. Schoknecht (2001) Off-road vehicles and vegetation patterning in a degraded desert ecosystem in Kuwait. *Journal of Arid Environments*, **49**(2): 413–427.

Cole, D.N. (1995a) Experimental trampling of vegetation: 1. Relationship between trampling intensity and vegetation response. *Journal of Applied Ecology*, **32**(1): 203–214.

Cole, D.N. (1995b) Experimental trampling of vegetation: 2. Predictors of resistance and resilience. *Journal of Applied Ecology*, **32**(1): 215–224.

Drewa, P. (2003) Effects of fire season and intensity on *Prosopis glandulosa* Torr. var. *glandulosa*. *International Journal of Wildland Fire*, **12**: 1–11.

Fuchs, E.H. (1997) Sediment removal by water following mechanical surface disturbance on Chihuahuan desert soils in New Mexico. M.S. Thesis, New Mexico State University.

Gibbens, R.P., J.M. Tromble, J.T. Hennessy, and M. Cardenas (1983) Soil movement in mesquite dunelands and former grasslands of southern New Mexico from 1933–1980. *Journal of Range Management*, **36**(2): 145–148.

Gillette, D.A., J. Adams, A. Endo, D. Smith, and R. Kihl (1980) Threshold velocities for input of soil particles into the air by desert soils. *Journal of Geophysical Research*, **85**: 5621–5630.

Gillette, D.A., and J. Adams (1983) Accelerated wind erosion and prediction of rates. In *Environmental Effects of Off-road Vehicles. Impacts and Management in Arid Regions* (R.H. Webb and H.G. Wilshire, ed.). New York: Springer Verlag, p. 97–109.

Herrick, J.E., J.W. Van Zee, K.M. Havstad, L.M. Burkett and W.G. Whitford (2005) Monitoring Manual for Grassland, Shrubland and Savanna Ecosystems Volume I: Quick Start, USDA-ARS Jornada Experimental Range, Las Cruces, New Mexico. http://usda-ars.nmsu.edu/monit_assess/monitoring.php

Hernando, A.M. (1999) Effect of military wheeled vehicles on soil compaction in the Chihuahuan desert. M.S. Thesis, University of Texas, El Paso.

Hillel, D. (1980) *Introduction to Soil Physics*. Orlando: Academics Press.

Jones T.L., M. Montez-Helu, and Q.B. Xie (undated 1996?) Ecological studies on McGregor range. Hydrologic studies task. Final report. Unpublished report.

Kade, A., and S.D. Warren (2002) Soil and plant recovery after historic military disturbances in the Sonoran Desert, USA. *Arid Land Research and Management*, **16**(3): 231–243.

Kozlowski, T.T. (1999) Soil compaction and growth of woody plants. *Scandinavian Journal of Forest Research*, **14**(6): 596–619.

Lovich, J.E., and D. Bainbridge (1999) Anthropogenic degradation of the southern California desert ecosystem and prospects for natural recovery and restoration. *Environmental Management*, **24**(3): 309–326.

Lunt, O.R., J. Letey, and S.B. Clark (1973) Oxygen requirements for root growth in three species of desert shrubs. *Ecology*, **54**(6): 1356–1362.

MacKay, W.P. and J. Herrick (1996) The impact of wheeled vehicle maneuvering on the flora and fauna of the chihuahuan desert: second report submitted to the U.S. Armyu Corps of Engineers. Unpublished report.

McIntyre, S., and S. Lavorel (1994) How environmental and disturbance factors influence species composition in temperate Australian grasslands. *Journal of Vegetation Science*, **5**(3): 373–384.

Mendoza, V.B., S.H. Watts, R.A. Guerrero, A.M. Hernando, M.P. Perez, M.D. Gaglio, and W.P. MacKay (1997) The impact of wheeled vehicle maneuvering on the flora and fauna of the Chihuahuan desert. Final report. CAGE number 9B980, U.S. Army Corps of Engineers, Construction Engineering Research Laboratory, Champaign, IL.

Milchunas, D.G., K.A. Schulz, and R.B. Shaw (2000) Plant community structure in relation to long-term disturbance by mechanized military maneuvers in a semiarid region. *Environmental Management*, **25**(5): 525–539.

Montes-Helu, M.C. (1997) Track-vehicle disturbance on rangeland and design of sap flow gauge for desert shrubs. Ph. D. Dissertation, New Mexico State University.

Musick, H.B., and D.A. Gillette (1990) Field evaluation of relationships between a vegetation structural parameter and sheltered against wind erosion. *Degradation and Rehabilitation*, **2**: 87–94.

Parton, W.J. (1978) Abiotic section of ELM. In *Grassland Simulation Model* (G.S. Innis, ed.). New York: Springer Verlag, p. 31–53.

Perez, M.P. (1999) Impact of military wheeled vehicles on water infiltration rates on Chihuahuan Desert soils. M.S. Thesis, University of Texas, El Paso.

Peters, D.P.C. (2002) Plant species dominance at a grassland-shrubland ecotone: An individual-based gap dynamics model of herbaceous and woody species. *Ecological Modelling*, **152**(1): 5–32.

Pidgeon, A.M. (2000) Avian abundance and productivity at the landscape scale in the northern Chihuahuan desert. Ph. D. dissertation, University of Wisconsin.

Pidgeon, A.M., N.E. Mathews, R. Benoit, and E.V. Nordheim (2001) Response of avian communities to historic habitat change in the northern Chihuahuan desert. *Conservation Biology*, **15**(6): 1772–1788.

Prose, D.V., S.K. Metzger, and H.G. Wilshire (1987) Effects of substrate disturbance on secondary plant succession; Mojave Desert, California. *Journal of Applied Ecology*, **24**(1): 305–313.

Stockon, P.H., and D.A. Gillette (1990) Field measurements of the sheltering effect of vegetation on erodible land surfaces. *Land Degradation and Rehabilitation*, **2**: 77–85.

Sun, D. (1990) Effect of plant age on tolerance of two grasses to simulated trampling. *Australian Journal of Ecology*, **16**: 183–188.

Sun, D. (1992) Trampling resistance, recovery and growth rate of eight plant species. *Agriculture, Ecosystems and Environment*, **38**: 265–273.

Sun, D., and M.J. Liddle (1991) Field occurrence, recovery, and simulated trampling resistance and recovery of two grasses. *Biological Conservation*, **57**: 187–203.

Taylor Soltero, H. (1996) Comparison of field methods and procedures to estimate termite activity in the northern Chihuahuan desert. M.S. Thesis, University of Texas, El Paso.

Trumbull, V.L., P.C. Dubois, R.J. Brozka, and R. Guyette (1994) Military camping impacts on vegetation and soils of the Ozark Plateau. *Journal of Environmental Management*, **40**: 329–339.

Valentine, K.A., and J.B. Gerard (1969) Life-history characteristics of the creosotebush, *Larrea tridentata*. *New Mexico Agricultural Experiment Station Bulletin*, No. 526: 1–32.

Webb, R.H. (1983) Compaction of desert soils by off-road vehicles. In *Environmental Effects of Off-road Vehicles. Impacts and Management in Arid Regions* (R.H. Webb and H.G. Wilshire, ed.). New York: Springer Verlag, p. 51–79.

White, P.S., and S.T.A. Pickett (1985) Natural disturbance and patch dynamics: An introduction. In *The Ecology of Natural Disturbance and Patch Dynamics* (S.T.A. Pickett and P.S. White, ed.). Orlando: Academic Press, p. 3–13.

Whitecotton, R.C.A., M.B. David, R.G. Darmody, and D.L. Price (2000) Impact of foot traffic from military training on soil and vegetation properties. *Environmental Management*, **26**(6): 697–706.

Wilshire, H.G. (1983) The impact of vehicles on desert soil stabilizers. In *Environmental Effects of Off-road Vehicles. Impacts and Management in Arid Regions* (R.H. Webb and H.G. Wilshire, ed.). New York: Springer Verlag, p. 31–50.

Yorks, T.P., N.E. West, R.J. Mueller, and S.D. Warren (1997) Tolerance of traffic by vegetation: Life form conclusions and summary extracts from a comprehensive database. *Environmental Management*, **21**(1): 121–131.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
November 2005

2. REPORT TYPE
Technical Report

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Determining Research Gaps in Disturbance Data for Fort Bliss and a Conceptual Model

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Tamara Hochstrasser, Debra Peters, and Jeffrey S. Fehmi

5d. PROJECT NUMBER
622720896

5e. TASK NUMBER

5f. WORK UNIT NUMBER
CNN-T081

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

USDA-ARS Jornada Experimental Range
Box 30003, MSC 3 JER
New Mexico State University
Las Cruces, NM 88003

8. PERFORMING ORGANIZATION REPORT NUMBER

ERDC/CERL TR-05-38

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Engineer Research and Development Center
Construction Engineering Research Laboratory
2902 Newmark Drive
Champaign, Illinois 61826-9005

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Numerous research and outside monitoring efforts have been completed for Fort Bliss, Texas. This report summarizes results from previous experimental studies on military disturbances on Fort Bliss and identifies research gaps in disturbance data. These studies (and others) are used to develop conceptual models of the impact of military disturbances on vegetation dynamics in arid lands.

15. SUBJECT TERMS
Disturbance
Fort Bliss
Recovery
Vegetation dynamics

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON / 19b. TELEPHONE NUMBER *(include area code)*
U	U	U	U	39	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. 239.18